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Novel image and non-image parameters for efficient characterisation of atmospheric Cerenkov Images

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Abstract

We make a comparative study of the classification potential of various image and non-image parameters which are measurable with the TACTIC array focal plane instrumentation.The image parameters include conventional Hillas parameters and multifractal dimensions and wavelet moments. Similarly the parameters derived from non-image Cerenkov data consist of pulse profile rise time and base width and the relative ultravoilet to visible light fluxes of the cerenkov events.It is shown by the artificial neural net approach that suitable combinations of these parameters can bring about an efficient segregation of various event types, even for modest sized data samples of progenitor gamma-rays and cosmic ray hadrons.

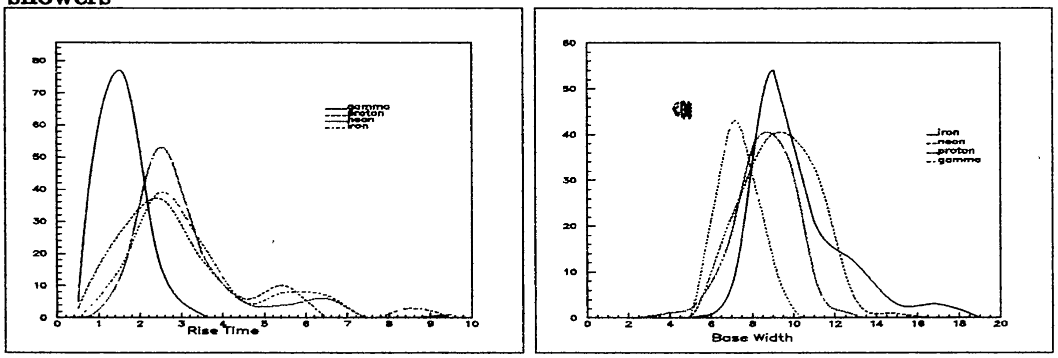
Key words: Multifractals, TACTIC, ANN,Wavelets, U/V and Time profiles

Introduction : The TACTIC (Tev Atmospheric Cerenkov Telescope with Imaging Camera) is a compact array of 4 telescopes which has been set up at Mt.Abu,Rajasthan for γ-ray astronomy work above TeV photon energies [1]. Here, comparatively weaker γ-ray signals from astronomical sources are sought to be picked up in presence of excessive cosmic ray background events through efficient classification of Cerenkov light images. The conventional image characterisation schemes are based on the use of various image geometrical parameters [2],like effective Length,Width and Orientation. We are presently examining new classification schemes employing in addition to multifractal and wavelet image parameters [3] and non-image parameters like arrival time profile of Cerenkov photons and its ultraviolet-to-visible light intensity ratio.

Simulation approach : Using the CORSIKA simulation code and after folding in the TACTIC detector configuration, we have generated Cerenkov data-bases comprsing 100 showers each for gamma rays (50 TeV),and Proton,Neon and Iron nuclei(100 TeV). The data generated are used for calculating the above-mentioned parameters are calculated.Using the ANN approach, we show that a judicious choice of all these parameters can separate better even relatively small samples of γ-ray and hadron events.

Hillas Parameters : We have calculated the following second moments for the simulated Cerenkov images:shape parameters like Length (L),Width (W) and Distance (D) and orientation parameters like alpha(α),Azwidth(A) and Miss(M).

Figure 1: Risetime and basewidth distributions of pulse profiles of γ,Proton Neon and Iron showers



Multifractal moments and Wavelets: Fractals are structures which display a self-similar behaviour and fractal nature is quantitively characterised by fractal dimensions. We have calculated multifractal moments of Cerenkov images by dividing the image into M=4, 16, 64 and 256 equally parts. The multifractal moments are given as

$$G_q \propto M^{\tau_q} \tag{1}$$

τ_q can be shown to be related to the generalized multifractal dimensions, D_q by

$$D_q = \frac{\tau_q}{q-1}\ ,\ q \neq 1\ , \tag{2}$$

Wavelets can detect both the location and the scale of a structure in an image. The wavelets are parameterized by a scale parameter and a translation parameter. Since we are analysing Cerenkov images which are fractal in nature, it is scaler parameter which is of interest to us than the translation parameter. The wavelet moment W_q is given as

$$W_q(M) = \sum_{j=1}^{M} \left(\frac{|k_{j+1} - k_j|}{N}\right)^q \tag{3}$$

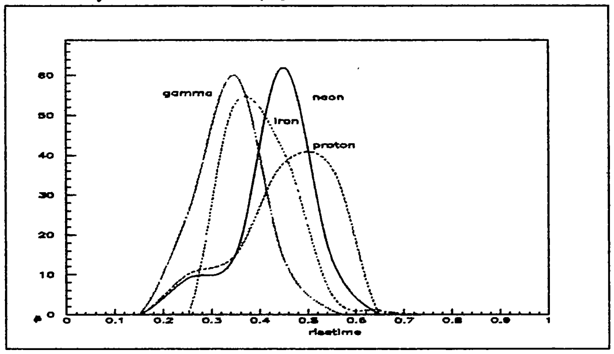
For a Cerenkov image from a TACTIC like system, we have

$$W_q \propto M^{\beta_q} \tag{4}$$

W_q shows a power-law behaviour with M and the slope of this line gives wavelet index β_q.

Time Parameters and U/V ratio: One of ouput parameters in the CORSIKA is the Cerenkov photon arrival time. The measurement of time begins with the first interaction and time taken by each photon as it traverses the atmosphere and reaches the observation level to the focal plane of TACTIC is measured. It is obseved from simulation studies that there are differences in the Cerenkov pulse profiles of different primary types which are related to the shower development initiated by γ-ray and nuclear-primaries in the

Figure 2: U/V ratio of γ,proton,neon and Iron showers



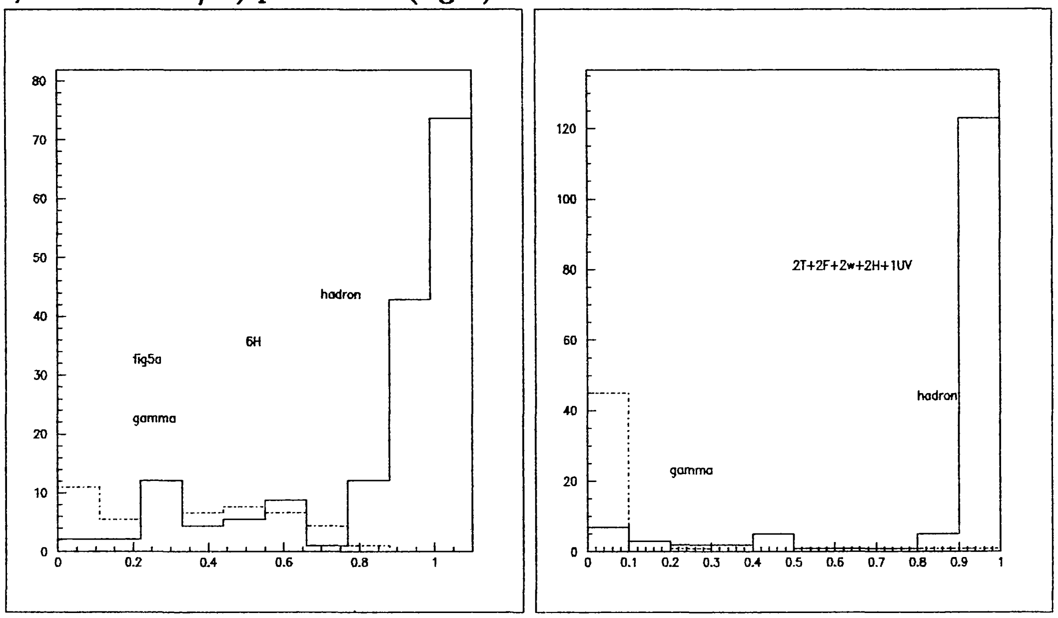
atmosphere.It is also found that the muon secondaries in the latter case have an important role in determining the Cerenkov pulse time-history. Thus the time profile of γ-ray primary is smooth profile with small rise time and base width while as the temporal profile of a hadron-origin has relatively longer rise time and base width as shown in the figure 1. We have also calculated the U/V ratio of each simulated image where U is the ultraviolet content (λ = 270-310 nm) of Cerenkov event and V is the corresponding visible content (λ = 310-500 nm).

The U/V ratio becomes important because in case of γ-ray initiated showers, the bulk of Cerenkov light is produced at higher altitudes and the resulting light will be U-component deficient because of atmospheric extinction effects whereas hadron showers will be U-component richer due to the presence of relativistic muons which penetrate deep into the atmosphere. The U/V is shown in figure 2, for a core disatance of 195 m.

ANN Studies: We have performed ANN studies (Jetnet 3.0 ANN package)by using Hillas parameters (W and D), fractal dimensions (D_4 and D_6) and wavelet moments (β_1 and β_2) ,Cerenkov pulse-profile rise time, base width and U/V intensity ratio as inputs. These parameters have been chosen by the method of minimum correlation. For all the exercises done here the ANN is trained with 50 independent events and tested for other 50 independent events for each species.The output values demanded are 0.0 -0.1 for γ-rays and 0.9-1.0 for hadrons events. The ANN resuts are shown in Figure 3 for two cases: one for only Hillas parameters the other includes fractal, wavelets,U/V and time parameters are also included.

Discussion and Conclusion: The present exploratory study is remarkable for its deliberate choice of extremely small data-bases of γ-ray and hadron events and for seeking their efficient segregation. While as a sufficiently large data-base may help to properly train a net for γ-ray /hadron classification using Hillas parameters alone for small data bases, only Hillas parametrization is not expected to work. The results presented here are remarkable in one respect, viz,γ-ray events are accepted at 90% level,as compared to (30-50%) γ-ray acceptance levels presently available through supercut image filter strategies. This very large acceptance levels for γ-rays provided by multiparameter approach,despite

Figure 3: ANN O/P with 6 Hillas parameters (left) and with all(2fractal,2 wavelet,2 hillas,2 time and U/V) parameters(right)



extremely small data-base size is of immense practical importance in ground based γ-ray astronomy in the UHE region(tens of TeV paticle energy range)

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